Bulk Acoustic Wave (BAW)

Bulk acoustic wave (BAW) filters [8-5] operate in a similar fashion to SAW filters in that they both operate through the use of resonators in which electrical signals are converted to acoustic waves. The difference between BAW and SAW filters is that in BAW filters the acoustic waves propagate through the substrate rather than along the surface before they are converted back into electrical signals. BAW filters have been gaining market share over SAW filters for mass-market RF applications because they can offer lower insertion losses and improved selectivity. BAW filter technologies include free-standing bulk acoustic resonators (FBAR) and solidly mounted resonators (SMR). BAW filters tend to be exhibit less sensitivity to temperature (by about two-fold) than SAW filters. A principle BAW drawback with respect to SAW filters is that they are more difficult to manufacture and thus slightly more costly.

At the present time, BAW filters are only available for use at GPS RF frequencies (and not for typical IF frequencies). GPS BAW filters are available in wider bandwidths at L1 (15 – 30 MHz) than SAW filters, but the wideband BAW filters tend to have slightly higher insertion losses. Figure 8-9 shows the selectivity of two representative RF BAW filters. The first (TriQuint 880273) has a specified minimum 3-dB bandwidth of 30-MHz bandwidth and a specified maximum insertion loss of 4 dB. The second (TriQuint 880085) has a specified minimum 3-dB bandwidth of 15 MHz, and a specified maximum insertion loss of 2.5 dB. The package size for each is 3.26 × 1.6 × 0.84 mm.

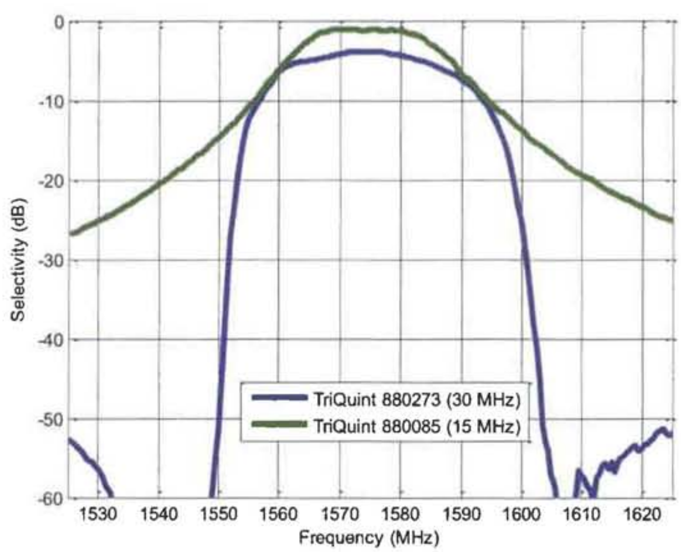

Figure 8-9. Selectivity of Two Representative BAW Filters

The 15-MHz BAW filter provides about 8 dB attenuation for the upper LightSquared carrier, and greater than 20 dB for the lower carrier. The 30-MHz BAW filter provides only around 6 dB attenuation for the upper carrier, but over 50 dB for the lower carrier.

Figure 8-10 shows the group delay responses for these two BAW filters. The differential group delay for the 30-MHz filter is around 24 ns and the group delay for the 15-MHz filter is just under 10 ns, both as measured across the specified minimum 3-dB bandwidth.

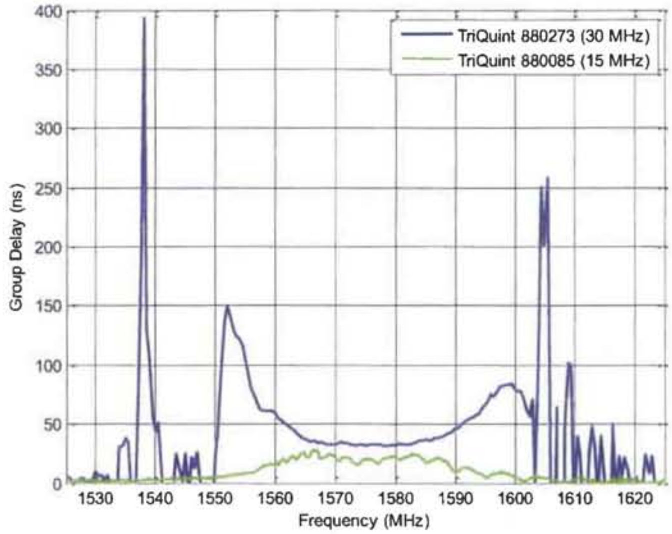

Figure 8-10. Group Delay of Two Representative BAW Filters

Cavity filters

Cavity filters [8-3] offer low-insertion loss and high out-of-band attenuation, with their main drawback being that they are extremely large and heavy. They operate using similar principles as dielectric resonators, except that they utilize an air-filled cavity within a conductor rather than a dielectric block as the microwave resonator.

Figure 8-11 shows the selectivity of one vendor's 20 MHz 1-dB bandwidth cavity filter (K&L Microwave part number 5C40-1575-U20-O/O) centered at 1575 MHz. The filter has an insertion loss of < 1.1 dB and provides ~25 dB of attenuation at 1555 MHz and over 50 dB of attenuation at 1536 MHz. However, this performance comes at the cost of size. This particular filter is 5.88 × 1.24 × 2.58 inches. A closely related model (5C42-1575-U20-O/O) provides even lower insertion loss with, with a maximum specified value of 0.7 dB, and slightly better selectivity and group delay characteristics at the price of growth in size to 9.38 × 1.94 × 2.52 inches. Because of their extremely large size and weight, cavity filters are only sporadically used for GPS equipment, and then only at RF, in niche applications such as very high-performance reference stations.

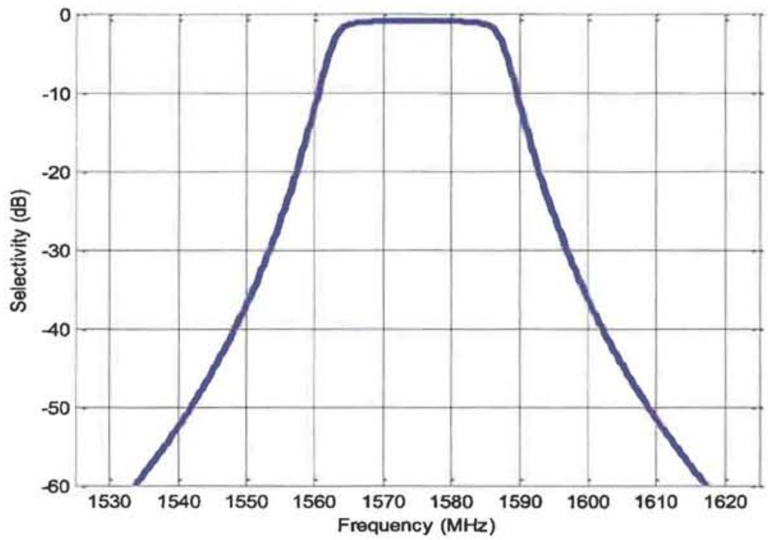

Figure 8-11. Selectivity of a 5-Section Cavity Filter with 20 MHz 1-dB Bandwidth Centered at 1575.42 MHz

The group delay for this particular product is shown in Figure 8-12. The differential group delay over the 20 MHz 1-dB bandwidth passband is approximately 25 ns.

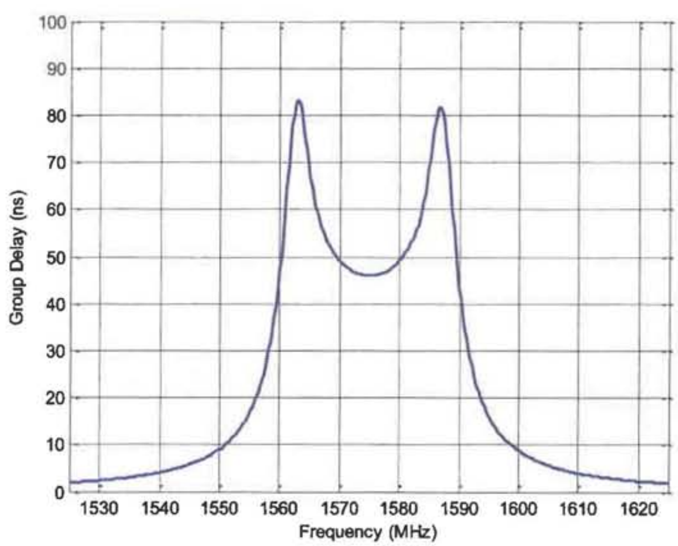

Figure 8-12. Group Delay of 5-Section Cavity Filter with 20 MHz 1-dB Bandwidth Centered at 1575.42 MHz.

Lumped Component Filters

Filters built using inductors, capacitors, and resistors are used at IF or baseband within many fielded GPS receivers. Some lumped component filters that only utilize inductors and capacitors are referred to as *LC filters*, which follows from the common engineering symbols for inductance (*L*) and capacitance (*C*). As examples of chipsets that utilize external discrete inductors and capacitors as their only means for IF filtering, see [8-6], [8-7], and [8-8]. The amount of attenuation provided by such filtering at the LightSquared frequencies depends on the design bandwidth of the LC filter and the order of the filter. As one example, [8-7] describes a GPS chipset that relies on a second-order, 15 MHz 3-dB bandwidth Butterworth LC filter centered at an IF frequency of 183 MHz. This filter provides ~10 dB of attenuation to the upper LightSquared carrier and ~40 dB to the lower carrier.

Active resistor-capacitor (RC) filters are also quite common in GPS chipsets. These offer the benefit that they can be implemented internal to the chip, see, e.g., [8-9].

Summary of Filter Technologies

Table 8-1 summarizes the filter technologies identified as being applicable for use for GPS RF applications. The most commonly used technologies – dielectric resonators, SAW, and BAW filters – are not capable of providing a significant amount of attenuation at the frequencies used for the upper LightSquared carrier (1545.2 – 1555.2 MHz). Even the most narrowband filters using these technologies at the GPS L1 frequency only provide an extremely limited typical attenuation of 4 – 8 dB at 1555.2 MHz. The minimum attenuation at this frequency is even less (nearly zero) when temperature variations are considered, especially for SAW and BAW filters. These common technologies, however, are capable of providing a more meaningful (~20 dB) attenuation of the LightSquared lower carrier (1526 – 1536 MHz)

Cavity filters are commercially available and are capable of providing much greater suppression of the LightSquared upper and lower carriers within GPS receiver RF processing. Such filters are rarely used today because they are significantly larger (~500,000 times greater volume than a SAW filter) and much more costly (~1000 times more costly than a SAW or BAW filter) than the other technologies.

Table 8-1. Summary of Commercially Available RF Filter Technologies for GPS L1

Technology	3-dB Bandwidth (MHz)	Insertion Loss (dB)	Attenuation for Upper/ Lower Light Squared Carrier (dB)	Differential Group Delay (ns)	Volume (mm^3)	Unit Cost in Large Quantity ($)
Dielectric resonator	24 MHz	2.2	4/20	4.2	2000	< 5
SAW	30 MHz*	1.4*	4/20	15	0.8	< 1

BAW	15 MHz*	2.5	8/20	10	4	< 1
Narrow-band Cavity	4 MHz	1.9	51/67	45	450000	500 - 1000
Wideband Cavity	30 MHz	0.7	8/50	18	600000	500 - 1000

*Commercially available GPS SAW filters are advertised with bandwidths from 2 – 2.4 MHz, but have much wider nominal 3-dB bandwidths. Their specified insertion loss, however, due to large deviations in their center frequency with temperature is only guaranteed over the much narrower advertised bandwidth.

IF filtering, using various commercially-available technologies is capable of much greater suppression of out-of-band and near-band signals provided that the receiver front-end can be adequately protected against saturation and intermodulation products from the RF filtering.

Feasibility of Adding Filtering to Fielded and New Equipment

Fielded GPS receivers can be divided into two categories:

- External antenna units – receivers designed to operate using separate antenna units that are connected to the receiver via a cable.
- Internal antenna unit or receivers integrated within another electronic device –receivers that utilize a built-in antenna (e.g., a handheld device with the antenna contained within the same case that houses the receiver) or include the GPS receiver within another electronic device (e.g., a GPS receiver engine within a mobile phone, iPad, or similar product).

Incorporating additional filtering to fielded receivers in the first category may be possible in some cases, but it is not likely that adding additional filtering to fielded receivers will be practical from a cost standpoint. Adding additional filtering to new products is more likely to be feasible/practical for both types.

Filtering within a well-designed GPS receiver is accomplished in stages. For example, Figure 8-13 shows an illustrative front-end design for an airborne GPS receiver and associated external antenna. The active antenna unit includes a passive patch element, limiter (to protect the antenna from, e.g., lightning), two dielectric resonator (ceramic) filters, and a LNA. The active antenna unit is connected to the receiver via a length of cable. The receiver unit itself includes a limiter, filtering, and LNA, followed by a mixer to downconvert the received signal down to some convenient intermediate frequency (IF). Following down-conversion, the IF signal is filtered by a surface acoustic wave (SAW) filter, amplified, and subsequently digitized by an analog-to-digital converter (A/D).

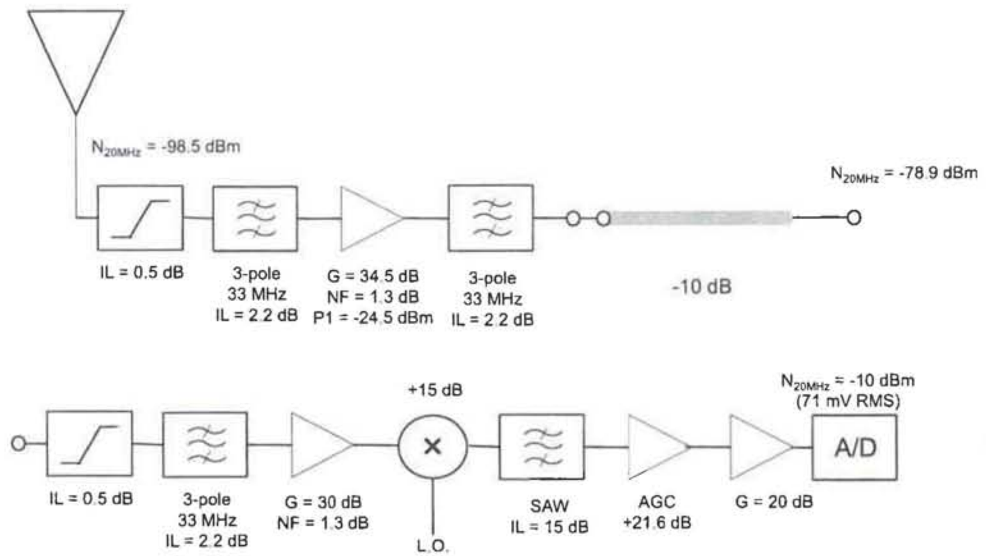

Figure 8-13. Illustrative GPS Receiver Design with an External Antenna Unit

It is important to note that the design in Figure 8-13 is only illustrative. Across the entire set of fielded GPS receivers, even constrained to just those that utilize external antennas, the designs vary greatly. Some configurations use passive antennas (i.e., the external antenna unit only contains the passive antenna element in a protective casing, or *radome*, with a connector). The amount of filtering within active antennas may vary tremendously from one receiver to another and the amount of filtering and filter technologies used within the receiver unit may also vary tremendously. Some receivers may use two or three stages of downconversion vs. the single-stage illustrated, etc. Some receivers sample the RF signal directly, achieving downconversion by intentionally undersampling relative to the Nyquist criteria.

Consider the challenge of adding additional filtering to the illustrative receiver design of Figure 8-13. If additional filtering was desired for installed equipment with this design, there would be few opportunities to add such filtering. As noted earlier, opening up the receiver is not likely to be cost-effective versus buying a new receiver. Thus, the only possible option would be to either replace the antenna with another unit that includes additional filtering or to place a filter in between the antenna and receiver units.

Increasing the selectivity of the active antenna would be extremely challenging since only one of the filter technologies now available for GPS equipment identified in Section 8.2 provides significantly better rejection of the upper LightSquared carrier frequency than the current design. The one filter technology that could improve selectivity is a cavity filter, which would not fit within the antenna unit.

The size constraint of the cavity filter might be accommodated by placing the cavity filter in between the active antenna and the receiver unit. However, the group delay differential characteristics of an ordinary cavity filter (see Figure 8-12) would be too large to meet the applicable performance requirements. A total group delay differential of less than 25 ns is specified for airborne antennas, and this budget is mostly already consumed by the active antenna in Figure 8-13. It might be possible to employ delay compensation within the cavity filter design, which is a customization offered by some microwave filter vendors, but whether such a product would meet all of the other applicable requirements remains to be determined. Also, if the additional filter is provided after the active antenna unit, this design modification provides no further protection to the active antenna LNA from saturation. For the particular design shown in Figure 8-13, the LNA will experience a 1-dB gain compression when it sees an input signal at -24.5 dBm. At even lower power levels, the third-order intermodulation products produced when the two LightSquared carriers pass through the LNA, which will act increasing non-linear as it nears saturation, have been observed during tests to cause significant degradation to some receivers.

For a new product, many degrees of freedom are opened. In this case, the entire receiver and antenna design could be optimized to meet an overarching set of requirements that included the need to tolerate high levels of interference at the LightSquared frequencies. In addition to adding filtering, there are other design modifications that may be necessary to facilitate coexistence with the proposed LightSquared network:

- Local oscillator phase noise and spurs – The fact that the receiver local oscillator (LO) does not have its power perfectly confined to the design frequency results in an effect called *reciprocal mixing* [8-10]. For example, if the intended LO frequency is 1505 MHz, this frequency is likely to be generated using a crystal oscillator operating at 10 – 50 MHz and a frequency synthesizer that multiplies the crystal frequency up to 1505 MHz. In a practical frequency synthesizer there will often be *reference spurs*, which means that the overall LO will produce a tone at 1505 MHz, but may have much smaller tones at integer multiples of the crystal frequency away from 1505 MHz as well. The reference spurs are typically at power levels that are 50 – 80 dB below that of the desired frequency output but may still result in significant problems when high-powered out-of-band signals are present at the receiver input. A carefully designed frequency plan and frequency synthesizer can mitigate reciprocal mixing problems. Developing workable frequency plans become much more difficult when powerful signals are anticipated near the GPS frequencies.
- Saturation – Many receiver front-end components, including LNAs, mixers, and analog-to-digital converters (and associated automatic gain control circuitry) can saturate due to strong out-of-band interference. Careful design of the entire receiver front-end chain is required to make sure that layered filtering is sufficient to ensure that all receiver performance requirements are met in the presence of a specified interference environment.

Given the wide variety of operational uses for GPS, however, the design requirements on receiving equipment also varies tremendously and there are some applications for which a practical receiver design will ***NOT*** be possible with the additional constraint of coexistence with 40,000 high-powered base stations broadcasting signals separated by only 20 MHz from the L1 carrier frequency.

Adaptive Antennas

Adaptive antenna processing is used for some military high-value platforms as a means to suppress interference. This technology requires the use of multi-element antenna arrays with typically 4 – 7 elements spaced an appreciable fraction of a wavelength apart. The physical antenna is thus very large, heavy, and expensive. There are limitations to the number of interference sources that can be simultaneously suppressed, which would likely be surpassed by the LightSquared network where hundreds of base stations could be simultaneously visible. Lastly, such technologies are export-controlled, which combined with the above limitations as a solution to the LightSquared coexistence problem makes this technology impractical.

System Changes

To counter the signal-to-noise degradation due to the presence of LightSquared signals, the GPS and WAAS L1 signals might be broadcast as higher power levels. This solution is not viewed as practical for several reasons. One, as noted earlier within this Report, the presence of LightSquared signals may result in some equipment being driven into a nonlinear mode of operation resulting in unpredictable performance. Increasing the GPS and WAAS signal power would not ameliorate this undesirable condition. Further, as with any space systems, the costs of broadcasting higher power levels are enormous and the timelines for implementation are very long. The GPS Block IIIA satellites have already passed through critical design review (CDR) and any modifications to their design would be extremely costly at this point in time. These satellites will be launched through 2018.

Operational Solutions

Not utilizing GPS L1 equipment in the vicinity of the LightSquared network may be a viable operational solution for a very small number of GPS users that either work only in remote areas in the United States where LightSquared towers will not be nearby, or in areas of the world outside of the United States.

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9. Subtask 9 - Mitigation Measures Applicable to LightSquared

Task Statement

Assess and recommend potential mitigation measures or techniques that are applicable to the LightSquared system based on the representative GPS receivers and the operational scenarios developed above including, for example, potential variations in emitted power, antenna gain pattern, and operating spectrum for the ATC base stations and mobile handsets.

This report addresses possible mitigation measures that could be implemented by LightSquared to reduce potential interference to GPS receivers while still providing a viable 4G service as required by the FCC. Five possible mitigation measures are examined, including increasing the frequency separation of LightSquared's transmitted signal relative to the lower edge of the RNSS allocated band at 1559-1610 MHz; reducing the transmitted power to reduce the magnitude of the interfering signal; modifying the base station antenna (either by narrowing the vertical beamwidth or increasing the antenna tilt so that less area is covered by each transmitting antenna); through the use of exclusion zones to maintain a minimum separation distance where this the installation is fixed; and by relocating the proposed LightSquared network operating frequencies to a more suitable band for high power terrestrial operations.

Frequency separation options in the MSS L-band

Confining LightSquared to the Lower Portion of the MSS L-band

Studies performed in the NPEF and the Industry Technical Working Group (TWG) indicate that for some GPS receivers there may be sufficient receiver selectivity to prevent receiver overload *if* the LightSquared signal is limited to just the lower portion of the MSS allocated band at 1525-1559 MHz. If the LightSquared deployment were to initially start with a broadband signal of 5 MHz (1526.3-1531.3 MHz) and then transition to a 10 MHz broadband signal from 1526-1536 MHz, the upper edge of the LightSquared signal would then be confined to the lower transmit channel alone and would remain approximately 23 MHz below the lower edge of the RNSS band. This increased frequency separation may be sufficient to avoid interference to some GPS receivers. An additional issue that may require further investigation if the LightSquared network is moved down in the MSS allocated band, is whether 4G broadband services that were an integral consideration in the FCC granting the January 26, 2011 waiver to LightSquared are viable if the available bandwidth is constrained to just 5 or 10 MHz versus 20 MHz.

It is unclear whether limiting the LightSquared signal below 1536 MHz would benefit all categories of receivers, particularly those that employ wide front ends or receivers that are designed to use current and future generations of GNSS systems (e.g., Galileo, Compass) which may have signals closer to the RNSS lower band edge than GPS. As an example, chamber testing with the NASA TriG space receiver which has a wide programmable front-end showed that a single LightSquared 5 MHz or 10 MHz signal at the lower end of the band had essentially the same interference impact as one at the high end of the band. For most terrestrial users it is difficult to establish distinct 'categories' because the same receiver may be used to support multiple applications each with a different set of requirements. Therefore, further investigation is recommended based on the frequency separation possibilities for LightSquared and the front end characteristics of GPS receivers if this option is considered viable based on other considerations.

Potential Impacts to in-band MSS Systems

Based on agreements with Inmarsat and certain other MSS providers, LightSquared intends to use the majority of MSS L-band spectrum for providing terrestrial broadband. FCC rules require that terrestrial use of the MSS spectrum should not preclude provision of MSS services (see FCC Part 25.149(a)(6)). LightSquared has indicated that it will maintain a dedicated minimum of 6 MHz of MSS spectrum in which to provide MSS. However, it is not clear what portion(s) of the MSS band will be used to provide such dedicated spectrum for space-based service.

In presentations to NTIA by the U.S. GPS Industry Council, two satellite broadcasts are noted that provide differential corrections for use by GPS systems (e.g., Deere's Starfire network and Omnistar). These channels are currently located in the MSS allocated band at 1535 and 1557 MHz and analysis by Deere indicates severe interference to reception of satellite signals from the LightSquared base stations due to the 90 dB differential in signal power between the base station transmit signal and the signal received on the ground from the MSS satellites. In these instances, it is unclear whether moving LightSquared down in the MSS band and away from the RNSS band would reduce the interference potential to applications where a differential correction is necessary, in addition to the basic GPS signals, to meet user requirements. It is noted that Inmarsat, in its comments on the LightSquared waiver request, indicated it will have to develop special filters to mitigate interference effects from the LightSquared base stations and that these filters "may" be able to reduce the interference to acceptable levels. However, there is as yet no technical evidence that this is feasible or viable.

Potential Impacts to Lower Adjacent Band Users

One possible effect of moving the LightSquared transmissions to the lower portion on the MSS allocated band is that it may increase the interference potential to Aeronautical Mobile Telemetry (AMT) flight test operations below 1525 MHz. The MSS ATC rules require that base stations located within radio line of sight of AMT receivers must be coordinated with test range frequency managers. Currently, the Aerospace and Flight Test Radio Coordinating Council (AFTRCC), which is responsible for non-Federal AMT coordination, is in discussions with LightSquared to determine coordination specifics for the LightSquared network. The original coordination agreement between AFTRCC and MSV, predecessor to LightSquared, did not contemplate the extensive terrestrial deployment now reflected in LightSquared's current plan. Any consideration of moving LightSquared farther down in the MSS allocated band should also consider the potential impacts to AMT operation, both in terms of increased potential interference and the additional coordination burden that would be placed on military and other Federal agency frequency managers and Federal test facilities.

Radiated Power limitations

Power Reduction Necessary to Mitigate Interference

The amount of transmitted power reduction necessary to prevent interference to GPS receivers varies as a function of the receiver characteristics, the scenario for which the device is used (e.g., ground-based, aviation, space-based), and the level of interference that degrades receiver performance beyond a certain amount (e.g., degrades C/No by 1 dB) for the specific receiver type in the scenario in which it is used. The specific receivers and their use scenarios are examined elsewhere in the NPEF Report. An important consideration is that what may be acceptable interference for one class of receivers or for one type of GPS application, may be unacceptable for one or more other GPS applications. Moreover, reducing the power per base station could reduce the interference potential to some GPS operations (e.g., ground-based receivers) but, at the same time, the denser network of base stations would increase the aggregate interference level for other applications (e.g. aviation or space-based receivers) as a consequence of having to increase the number of base stations to maintain the same overall coverage area.

Some categories of GPS receivers, such as those used for aviation in safety-of-life applications, have fairly well-defined levels of interference tolerance. For other receiver types or categories, a determination of what constitutes a tolerable level interference[6] is more complex. For example, if the definition of harmful interference[7] as stated in domestic (FCC) or international (ITU) rules were used to establish tolerable levels of interference, non-aviation safety-related applications would need to define at what level these services were "endangered" and other GPS applications would be subject to disruption at harmful interference levels. In addition, many terrestrial applications such as E-911, vehicle navigation for emergency responders, etc, while not formally considered to be 'safety-of-life' they are nevertheless critical for public safety.

In order to establish the levels of tolerable interference for GPS receivers, metrics such as at what interference level accuracy and other baseline functions of the receiver start to degrade, are necessary. These have largely been, or are being, identified during the testing process. From these metrics, and based on other factors such as other known interference source levels, tolerable levels are defined for each receiver class and type of receiver. While recognizing that the different use scenarios and differing GPS receiver characteristics drives different levels of tolerable interference, reducing the radiated power from LightSquared base stations to that which protects the most susceptible GPS operations avoids choosing which GPS operations will be protected and which will be subject to disruption.

The tolerable levels of interference based on the receiver types and applications are listed below. The level by which LightSquared base station power would need to be reduced to protect the most susceptible GPS operations is listed as the necessary level overall.

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[6] In some cases, such as advanced scientific applications, setting a "tolerable" level could lead to undesired consequences, such as limiting future innovation and development of advanced applications.

[7] *Harmful Interference.* Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations. (CS)

Effect on Deployment of LightSquared Network:

Any reduction in the transmitted power of the LightSquared base stations will invariably affect the coverage per base station, the performance (capacity and speed) of the LightSquared network, or both. If it is assumed that there are minimum required performance standards that must be achieved to provide 4G LTE service to cover approximately 92% of the U.S. population once the LightSquared network is fully deployed (end of 2015), the number of base stations would need to be increased to make up the reduced coverage area per base station.

If the power reduction needed to mitigate interference to GPS operations is relatively modest, perhaps less than 10 dB, it may be possible to implement such a reduction and still enable LightSquared to provide an economically feasible broadband network. However, if the required reduction in power is significant, the ability to deploy an economically viable broadband terrestrial network may not be feasible.

Impact to Providing 4G Performance

Any reduction in power transmitted by the LightSquared base stations would result in some impact to the network's ability to provide terrestrial broadband services nationwide. All other factors being the same, network capacity and speed are primarily functions of the available signal power and bandwidth. Assuming the LightSquared network as currently planned was optimized to provide 4G broadband service, any reduction in power per base station would, at some point, have a negative impact on the capacity and performance of the network. It is not known how much of a reduction of LightSquared transmit power could be accommodated without negatively impacting network performance as there would normally be some margin planned into the network by design.

Feasibility of Implementing

The feasibility of using power reduction for the LightSquared base stations as a mitigation measure is dependent on the magnitude of the power reduction required to avoid interfering with GPS reception. If the required power reduction is modest, which is not known at this stage, and then this mitigation option may prove to be a viable course of action. If the required power reduction is significant, it may make this option unworkable for several reasons (e.g., cost to add base stations, limitations on network capacity and performance, ability to provide nationwide broadband services as required by FCC in the Harbinger Order).

Antenna Modifications

Modifications to base station antenna patterns (e.g., through use of narrower and otherwise shaped beams) or increasing the downward tilt angle of the antenna from the currently planned 2 degrees to reduce the area affected by LightSquared base stations, would have similar effects on coverage area as reducing the power per base station, albeit without the additional impacts on overall network performance because the assumed transmit power per base station would remain the same. Since the number of base stations needed to provide the same coverage would increase, the impact of this mitigation technique would likely be to increase the overall interference potential rather than decrease it for the majority of GPS applications.

Effectiveness and Applicability

Increasing the downward tilt of antenna reduces the range of the transmitted interfering signal but increases the level of interference within the reduced coverage area. While this technique may have some utility if the objective was to protect a fixed receive site in a particular direction, it would likely increase the potential interference to the vast majority of GPS users because the interference power per area covered would increase and the overall number of base stations would also necessarily increase if the same coverage area were assumed. Similar to the consequences of increasing the number of base stations because of reduced power per base station, the interference potential to GPS operations that are most susceptible to aggregate interference (e.g., aviation and space-based receivers) would also increase.

Likewise, modifying the radiation pattern of the transmit antenna would only be effective if the objective was to reduce the interfering signal power in a particular direction, such as for specific fixed GPS receive sites. For other GPS applications and use scenarios that are not permanently fixed, the technique would not be effective.

Effect on Deployment of LightSquared Network

Any reduction in the coverage area for individual LightSquared base stations, either by increasing the downward tilt of the antenna to limit the range of the interfering signal or through use of narrower or shaped beams to reduce interference in a particular direction, would result in an overall increase in the number of base stations to maintain the same coverage. At some breakpoint, the costs associated with the increased number of base stations will negatively affect the viability of providing a nationwide broadband terrestrial network.

Feasibility of Implementing

The utility of using antenna modifications for the LightSquared base stations as a mitigation measure is marginal and applicable only in cases where it is necessary to reduce the interfering power in one direction. The potential benefits of this mitigation option for widespread use likely would be negated as a practical matter by the increased costs associated with implementing this option. However, for site-specific interference mitigation, it may be feasible and have some utility for avoiding interference to GPS operations.

Exclusion Zones

Effectiveness and Applicability

Use of exclusion or keep-out zones around individual receive sites would have the effect of maintaining a minimum distance between the interference source (LightSquared base station) and the GPS receiver. This mitigation technique is only applicable to <u>fixed</u> receive sites and would have minimal utility otherwise. For fixed GPS receive sites, maintaining a minimum distance between interference source and victim receiver is a well-established mitigation technique. Note that the technique would not be of value in mitigating RFI from LightSquared user handsets.

Feasibility of Implementing

The utility and feasibility of using exclusion zones as a mitigation technique must be evaluated on a case-by-case basis. For example, if to avoid interference to a specific receive location required that LightSquared transmitters were prohibited from serving a large metropolitan area; it would likely not be deemed feasible because of the impacts on LightSquared's coverage area and ability to provide service to large segments of the local population. For example, this could impact GPS receivers that are used in applications critical to public safety (E911, navigation of emergency response vehicles, etc.) where loss of GPS service could result in loss of life.

Moving terrestrial broadband to a different frequency band

Because not all of the interference mitigation techniques discussed previously would prevent interference in all GPS use scenarios, it may be desirable to relocate the LightSquared broadband operations to a different frequency band. There are numerous possibilities that could be considered for a terrestrial broadband network, however because LightSquared is basing their broadband network on a hybrid terrestrial-satellite model, discussion in this section is limited to MSS bands where MSS ATC is currently permitted. However, under the President's Broadband Initiative, up to 500 MHz[8] will be made available for wireless broadband applications in the next 5-10 years and some of the bands already identified via the "Fast Track" process[9] may also be suitable for relocation of the LightSquared network and could be examined in addition to the bands discussed below.

Possible Alternative Frequency Bands

Other than the MSS L-band, there are two MSS bands where terrestrial augmentation has been authorized by FCC. These bands are listed below:

Big LEO band

1610-1626.5 MHz (uplink)/2483.5-2495 MHz (downlink): There are two systems operating in the Big LEO band; Iridium and Globalstar. Of these systems, Globalstar uses the typical uplink channel in the 1610-1626.5 MHz band and downlinks in the 2483.5-2495 MHz band (note that the downlink band was reduced some time ago by FCC action to facilitate introduction of terrestrial wireless services). Iridium uses the upper portion of the 1610-1626.5 MHz on a

[8] Presidential Memorandum: Unleashing the Wireless Broadband Revolution, dated June 28, 2010

[9] See: FCC DA-11-444. The bands 1695-1710 and 3550-3650 were identified by NTIA as becoming available within the next 5 years and other bands (e.g., 1755-1850 MHz) are being evaluated for possible reallocation.

bidirectional basis by time-duplexing between uplink and downlink signals, with the uplink allocated on a Primary basis and the downlink on a Secondary basis. Iridium has never applied for MSS ATC authorization, presumably because of the way in which they use the MSS band, which could result in self-interference. Globalstar had received authorization to provide MSS ATC in the Big LEO band but was unable to satisfy FCC "gating criteria" within a prescribed time limit and had their authorization cancelled by the Commission. There are currently no MSS ATC providers in the Big LEO band.

2 GHz MSS Band:

2000-2020 MHz (uplink)/2180-2200 MHz (downlink): Two MSS ATC providers have been authorized to provide service in the 2 GHz band; Terrestar and DBSD (formerly ICO, a spin-off on Inmarsat). Neither Terrestar nor DBSD have proven successful in deploying an MSS ATC system and both are currently in significant financial difficulty and have been, or are currently in, bankruptcy. The FCC has recently added new terrestrial service allocations to the 2 GHz MSS band that would facilitate use of this band by systems such as that proposed by LightSquared. In addition, since testing has shown that even one base station could interfere with GPS reception at considerable distances, rationalizing the terrestrial broadband operations by consolidating them in the 2 GHz band could resolve existing interference issues as well. In this case, the MSS L-band allocation would remain as a satellite component of the network and would be accessed via dual-mode (terrestrial/satellite) handsets with terrestrial operations consolidated in the 2 GHz MSS band.

FCC Report and Order on Making Spectrum Available for Terrestrial Broadband

On April 6, 2011, the FCC issued a Report and Order that makes all three of the MSS bands (L-band at 1525-1559 MHz (downlink) and 1626.5-1660.5 MHz (uplink) available for increased use for terrestrial broadband applications. While flexibility was added via spectrum leasing arrangements for the Big LEO band and 2 GHz MSS band, the FCC took additional measures for the 2 GHz band to facilitate use by terrestrial systems, including making new Primary allocations to the terrestrial Fixed and Mobile Services in the band.

Effectiveness in Mitigating the Interference to GPS Receivers

Because both the Big LEO and 2 GHZ MSS band downlinks are significantly removed from the GPS L1 band, the interference effects caused by the LightSquared proposed network at L-band (e.g., GPS receiver front end overload) would not be a concern. Thus relocating LightSquared's proposed network to either of these other MSS bands would be an extremely effective means of ensuring that GPS L1 receivers are not degraded or disrupted. In addition, Federal agencies and civilian GPS interests were successful in negotiating the same out-of-band emission limitation for all FCC authorized MSS ATC systems in both the Big LEO and 2 GHz MSS bands so that emissions limits into the GPS L1 band would be maintained. The FCC has also included, in their April 6, 2011 MSS ATC Order, text that requires that any use of the MSS ATC bands for terrestrial applications via lease arrangements must conform to the existing MSS ATC rules and all conditions imposed on the authorized MSS ATC providers, meaning the emission constraints would carry forward to any new users if DBSD or Terrestar were to lease their spectrum to terrestrial users. Service rules for the new Fixed and Mobile allocations have not yet been developed. It is also worth noting that existing conditions of the MSS ATC authorizations at 2 GHz include provisions to coordinate with Federal agency satellite operations in the adjacent 2200-2290 MHz downlink band so that existing provisions should protect these Federal agency operations. These protections should be included in any new service rules developed for the Fixed and Mobile Services as necessary.

Effects on LightSquared Network Deployment

The primary impacts to LightSquared, at least in terms of its terrestrial-only network, would be cost increases and delays in implementation. A complicating factor for moving the satellite component of the network is the satellites already on orbit only transmit in the L-band; however, design of multi-band handsets that could span the range between the 2 GHz MSS and the L-band is commonplace in the cellular industry and so not an insurmountable obstacle. Because the build-out schedule for the LightSquared broadband network was a condition imposed by FCC during the Harbinger acquisition of SkyTerra (now LightSquared), it is presumed the FCC can grant any relief to that build-out schedule that might be necessary to allow a transition of the terrestrial-only portion of the LightSquared network to a more suitable MSS band such as the 2 GHz or Big LEO bands.

Cost could become a significant consideration for LightSquared in that they were able to secure the SkyTerra spectrum resources for significantly less than it would have cost to bid at an FCC spectrum auction for terrestrial mobile service spectrum as would typically be required for wireless operators. The cost differential to acquire a 2 GHz MSS ATC licensee compared to the acquisition cost that Harbinger paid for SkyTerra is not known. However, based on wireless spectrum demand alone, it seems reasonable to assume the price may be somewhat higher now than a year ago when Harbinger acquired SkyTerra. On the other hand, operating in 2 GHz and avoiding disruption of RNSS systems would ease international deployment and enable a larger addressable market and associated lower costs due to economies of scale.

Feasibility to Implement

The primary differences between using the L-band spectrum for terrestrial broadband and using spectrum at either 2 GHz or the Big LEO band would be cost and schedule concerns associated with transitioning to one of these bands from the current plans at L-band. In addition, if the terrestrial-only portion of the network uses another frequency than that used by the satellite component, dual-frequency receivers would need to be used for hybrid (satellite-terrestrial) network access, which would require modification to the existing hybrid terminals for dual-band operation (as is typical of many cellular phones that operate with global allocations that are in different frequency ranges). All other considerations being equal, the 2 GHz MSS band may be the more attractive option for extensive terrestrial operations such as that proposed by LightSquared, particularly given the new terrestrial allocations made recently by FCC for that band in particular.